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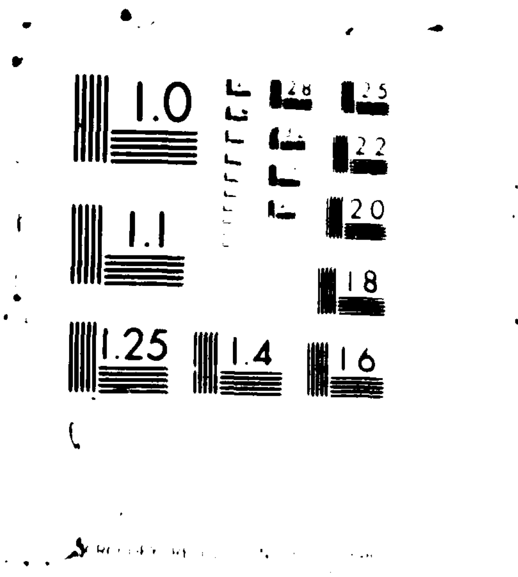
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This is a report of a three-day workshop on the applications of biotechnology to aerospace materials held in Dayton OH, 27-29 August 1986. The workshop was organized by the University of Dayton Research Institute and received support from AFOSR-NC and AFWAL/MLBC. Areas covered included biotech approaches to the synthesis of chemicals, bioelectronics, biomining, and biodegradation of materials. Participants included representatives from AFOSR and the Air Force Laboratories, and the biotech and aerospace industries. Keywords:

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POTENTIAL APPLICATIONS OF BIOTECHNOLOGY TO AEROSPACE MATERIALS

Final Conference Report

Grant No. AFOSR-86-0183

November 1986

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UNIVERSITY OF DAYTON
RESEARCH INSTITUTE
DAYTON, OHIO 45469-0001

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This report stems from a three-day workshop on the Potential Applications of Biotechnology to Aerospace Materials held at the Marriott Hotel in Dayton, Ohio and sponsored by the University of Dayton Research Institute (UDRI). Technical support was given by the Air Force Office of Scientific Research (AFOSR) and the Air Force Wright Aeronautical Laboratories/MLBC. The speakers and participants consisted of aerospace materials scientists and engineers and biotechnology experts. A program and list of attendees are attached in Appendices A and B, respectively.

The definition of biotechnology used by the Air Force Aerospace Materials Laboratory is the use of biological organisms and/or biological molecules to produce or aid in production of a commercial product. This is a broad definition of a relatively young science which has received much attention from medical and agricultural industries. Interactions, however, between materials and specialty chemical industries and biotechnology industries to use biotechnology for nonbiological end applications has been slow. This may be due to a communication gap which results from a language barrier and a lack of fundamental understanding between technologies.

An initial investigation into the biotechnology community uncovered five major areas of interest and possible benefits to the aerospace materials industry, which led to the organization of this workshop. These areas included: (1) utilization of biological organisms to recover difficult-to-obtain strategic metals and produce fine powders; (2) utilization of biological organisms or isolated enzymes to provide novel chemical approaches in the production of specialty chemicals and materials; (3) utilization of biological molecules for electric and optical properties; (4) utilization of biological organisms for degrading materials and waste products; and (5) examination of natural products and materials for structure/property relationships and novel design concepts.

The workshop was designed as a first step to investigate the above areas by bringing the two technologies together to exchange ideas and information. The goals of the workshop were to: (1) establish a dialogue between the biotechnology community and the aerospace community; (2) identify potential applications of biotechnology to aerospace materials needs; (3) estimate a time frame and feasibility for each application; (4) determine advantages of utilizing biotechnology over conventional approaches; (5) suggest roles of the Air Force and private sector for future biotechnology research; and (6) make recommendations for future biotechnology/aerospace materials interactions.

The workshop was divided into three sections. The first section consisted of a series of lectures designed to help break the language barrier between the two technologies. The second section involved open discussions between the two technologies to exchange ideas and information on the potential for using biotechnology to aid in aerospace materials development or processing. The specific topics chosen for discussion included: (1) biosynthesis of chemical intermediates; (2) bioelectronics; (3) biologically assisted mining and purification of strategic metals; and (4) biodegradation of paint for paint stripping. The third section involved a summary discussion of the 10 biotechnology experts to develop recommendations for future interactions. The following is a report of the discussion groups and recommendations presented at the workshop.

Biomining

Biomining is the utilization of biological organisms to accumulate or purify metals. There are two possible biological methods of recovering metals. The first is bioleaching. Bioleaching concentrates metals by oxidation reactions to produce a more soluble product. The direct method involves the oxidation of metal sulfide to metal sulfate:[1]

$$ms + 2O_2 \xrightarrow{\text{bacteria}} msO_4$$

where m is a bivalent metal. In the indirect method of bioleaching, the metal sulfide is oxidized by ferric ion:

$$ms + 2Fe^{+3} \longrightarrow m^{+2} + 2Fe^{+2} + s$$

The microorganisms in this case are responsible for the reoxidation of ferrous iron to ferric iron and the oxidation of elemental sulfur to sulfuric acid. An example of indirect bacterial leaching activity is uranium ore leaching where tetravalent uranium is oxidized to hexavalent uranyl sulfate[2]

$$UO_2 + Fe_2(SO_4)_3 + 2H_2SO_4 \longrightarrow H_4[UO_2(SO_4)_3] + 2Fe_2SO_4$$

The main organisms involved in bioleaching are rod-shaped chemoautotrophic bacterium, thiobacilluo ferrooxidan and thiobacillus thiooxidans. These organisms are currently used in copper and uranium recovery from low-grade ores and industrial wastes. Other organisms that have demonstrated ability to solubilize metals include heterotrophic bacteria, molds, yeast, algae, and protozoa.

The second possible biological route for recovering metals is biosorption. The biological absorption and/or adsorption of heavy metals has been well documented in many living as well as nonliving organisms.[(3)] Organisms found that accumulate inorganic ions include bacteria, algae, and fungi. Some examples of the metals that have been found are uranium, magnesium, iron, molybdenum, selenium, radium, and cadmium.

The possibility exists of using bioleaching or biosorption for recovery of strategic and precious metals such as cobalt, nickel, zinc, arsenic, gallium, cadmium, scandium, erbium, yttrium, and titanium. The potential advantage of biomining is the ability to concentrate metals from low-grade materials, where conventional metal recovery is expensive and ineffective. The present information on biomining specific strategic metals is limited. Recommendations for future studies include complete literature surveys and preliminary experimental assessments on the desired metals.

Another potential application of biomining to aerospace materials is assistance in producing submicron size powders. The accumulation of metals in some microorganisms is in the form of small granules (<1 μm). The recovery of such small particles could be useful for powder metallurgy; however it is not clear if this could compete with or aid current technology.

Bioelectronics

There are many biological molecules which demonstrate novel electronic properties and could have potential applications to aerospace materials. Some biomolecules or biomaterials can form liquid crystals and retain a high degree of charge separation necessary for photon and electron transfer. Those materials display higher nonlinear optical properties than many other known organics. Some biomolecules, for example bacteriarhodopsin, have large two-photon absorptivities and respond to laser light within 1 psec. Other molecules, such as long-chain Schiff base salt polyenes and ion doped electron transfer polyenes, display broad band radar-absorbing properties which exceed ferric-based epoxies.

The future applications of bioelectronics presented at the workshop include:

1. High-speed molecular-based computer circuit
2. High-speed, high-density optical disk storage
3. Nonlinear optical materials
    - laser hardening (carotenoid excimers, two-photon absorption by retinyl polymers)
    - upconversion using Langmuir Blodgett films of biomolecules
4. High-speed (6 Hz) analog-to-digital conversion
    - digital radar analysis
    - optical pattern recognition
5. High-speed 2D transformations
    - parallel processing using photochemically active thin film bioorganics

6. Radar-absorbing materials
   - lightweight tunable materials (ex. retinyl polymers, Schiff base salt polyenes)
   - doped electron conducting polymers

7. Single molecule detection
   - optically coupled reactive molecule electronic devices

The areas recommended for future investigation relating to aerospace materials include nonlinear optics, laser-hardening materials, radar-absorbing materials, and high-speed analog-to-digital conversion. These areas in bioelectronics appear to be very interesting and promising. Further investigations and feasibility studies are recommended.

Biodegradation

Presently much research is being conducted in the area of biodegradation of toxic and hazardous waste products. The discovery of microorganisms which live in adverse conditions (such as dump sites) has revealed bacteria which can degrade PCBs or accumulate toxic metals. The ability to manipulate the genetic code to enhance or block an enzyme provides many potential prospects in the area of biodegradation. This area of toxic and hazardous waste disposal is of major concern to the Air Force, however is is not a key focus of the Materials Laboratory.

The main application to the Aerospace Materials Laboratory and topic for discussion at the workshop was biodegradation of paint for paint stripping aircraft. The present method of paint stripping damages many of the new advanced composite materials being used in aircraft. New methods are being investigated for removal of the paint without damage to the aircraft.

The biodegradation of the polyurethane paint would involve the application of enzymes possibly in the form of a foam to degrade the paint conceivably by hydrolyzing the carbonate bond in urethane. The problems involved would be identifying all components of the paint including polyurethane structure, primer chemistry, paint chemistry, and other additives including anti-microbial agents, control of the biodegradation so that it occurs only when needed, and control of the speed of the reaction so that degradation occurs rapidly. Recommendations for investigation in the area of biodegradation for paint stripping aircraft includes literature searches and discussions with paint industries. The predicted probability of success however seems questionable. Much more information is needed to evaluate this area.

Biological Synthesis of Chemicals

The utilization of biological organisms or isolated enzymes to provide novel chemical approaches in the production of specialty chemicals and materials may have numerous applications in the Aerospace Materials Laboratory. Enzymes are the catalyst for all biological reactions and can be classified into six groups: (1) oxidoreductases (catalyzing oxidation-reduction reactions); (2) hydrolysis (catalyzing hydrolysis reactions); (3) transferases (catalyzing transfer of functional groups); (4) lyases (catalyzing isomerization reactions); (6) ligases (catalyzing formation of c-c, c-o, c-s, and c-n bonds).

Advances in the area of enzyme technology and protein engineering have increased the applications of biocatalysts in preparative chemistry. Some of these advances include computer modeling of enzymes to determine structure/property relationships, redesigning enzymes by site directed mutagenesis, and using organic solvents instead of water as a reaction medium.

Enzymatic reactions combined with synthetic chemistry may produce many new materials unattainable or impractical by synthetic chemistry. An example is the production of dihydrodiol from benzene using an enzymatic reaction in a microorganism. The dihydrodiol is then used as a precursor for polyphenylene, a rigid rod polymer.[4]

Another approach for using biological organisms to produce specialty chemicals and materials is to increase and/or modify the production of natural chemicals and materials they produce. A number of materials were listed at the workshop that could be of significant interest to the Materials Laboratory including acetylene compounds, adhesives, structural materials, lubricants, and ceramics.

The biosynthesis of new chemicals and materials appears to be an extremely promising area. Recommendations for future investigations include selection of specific compounds of interest (ex. natural acetylene) and completing feasibility studies to determine properties and processing characteristics. Other recommendations include a separate workshop concentrating on biosynthesis of chemicals and materials with more input from the Materials Laboratory on the specific chemicals, materials, and processing parameters needed. As biotechnology capabilities grow, the applications for producing novel materials and chemicals will also increase.

Biotechnology is still an extremely young science, however it has great potential. Of the areas discussed at the workshop (biomining, bioelectronics, biodegradation for paint stripping, and biosynthesis of chemicals and materials), the two that appear to show the most promise are biosynthesis of chemicals and materials and bioelectronics. The advances in protein engineering and enzyme technology should lead the way for design of new enzymes and biomolecules of choice to form new chemicals and materials with unique properties.

The general recommendations from the workshop were to continue communication between the Air Force and biotechnologists and to collect and circulate pertinent literature. Suggestions for continued interaction included workshops on more specific topics and white papers. The panel members requested more information on the materials and chemicals needed, explanation of the properties the materials and chemicals need, explanation on how the materials are presently made, and the problems involved in obtaining them including cost.

In conclusion biotechnology shows great potential and should have a positive impact on aerospace materials processing and development. Used as a processing tool, biotechnology will allow for production of novel materials at possibly cheaper costs. The combination of biotechnology and synthetic chemistry will prove to be a very fruitful adventure.

References

1. R. F. Decker, "Biotechnology/Materials: The Growing Interface," Metall. Trans. A, 17A(1), pp 5-30, January 1986.

2. Arpad E. Torma, "Biohydrometallurgy as an Emerging Technology," Biotechnology and Bioengineering Symposium, No. 16, 1986.

3. N. Friis and P. Meyer-Keith, "Biosorption of Uranium and Lead by Streptomyces and Longwoodensis," Biotechnology and Bioengineering, Vol. 28, January 1986.

4. D. G. H. Ballard, A. Courtis, I. M. Shirley, and S. C. Taylor, "A Biological Route to Polyphenylene," J. Chem. Comm., pp 954-55, 1983.

FINAL AGENDA

WORKSHOP ON POTENTIAL APPLICATIONS OF BIOTECHNOLOGY
TO AEROSPACE MATERIALS PROBLEMS
27-29 August 1986
Dayton Marriott Hotel
Dayton, Ohio

Tuesday, 26 August 86

7:00-9:00 p.m.	Wine and Cheese Reception

Wednesday, 27 August 86 - Technical Presentations - Present Biotechnology Capabilities/Aerospace Materials Problems

7:30 a.m.	Coffee/Donuts/Registration
8:25	Welcome - Ms. Becky Schiavone, UDRI
8:30	Introduction - Dr. Tony Matuszko, AFOSR
8:45	The Present and Future of Aerospace Materials - Dr. Harris Burte, Chief Scientist, Materials Laboratory
9:45	BREAK
10:00	Aerospace Materials Problem Areas with Possible Biotechnological Solutions - Dr. Fred Hedberg, Materials Laboratory
11:00	Overview of Molecular Biology - Dr. Stephen Edelson, Genencor Inc.
11:45	LUNCH - Introduction of Participants and Attendees
1:00 p.m.	Applications of Biotechnology in Synthetic Chemistry - Dr. Masato Tanabe, SRI
1:45	Large Scale Production Methods - Dr. Herbert Klei, University of Connecticut
2:15	Bioelectronics - Dr. Robert Birge, Carnegie-Mellon University
2:45	BREAK
3:00	Biologically Assisted Mining and Purification - Dr. Arpad Torma, New Mexico Institute of Mining and Technology
3:30	Biodegradation - Dr. David Gibson, University of Texas
4:00	General Discussion
5:00	ADJOURN
6:00	Banquet Presentation - "Air Force Basic Research" (AFOSR)

Thursday, 28 August 86 - Discussion Sessions - Future Possibilities for Biotechnological Impact on Aerospace Materials Needs

7:45 a.m.	Coffee/Donuts
8:15	Introduction to Discussion Sessions - Dr. Fred Hedberg, Materials Laboratory
8:30	Natural Products with Aerospace Applications Leader: Dr. Saul Neidleman, Cetus
9:45	BREAK
10:00	Biosynthesis of Chemical Intermediates for Aerospace Materials Leader: Dr. Daniel Abramowicz, General Electric
11:15	Biodegradation for Paint Stripping Leader: Dr. David Gibson, University of Texas
12:15 p.m.	LUNCH - Review of Morning Session and Suggestions for Afternoon Discussions
1:15	Bioelectronics Leader: Dr. Robert Birge, Carnegie-Mellon University
2:30	BREAK
2:45	Biologically Assisted Mining and Purification of Strategic Metals Leader: Dr. Arpad Torma, New Mexico Institute of Mining and Technology
4:00	General Discussion
5:00	ADJOURN

Friday, 29 August 1986 - Draft of Conclusions and Recommendations

7:45 a.m.	Coffee/Donuts
8:00	Drafting Session - Leaders: Ms. Becky Schiavone, UDRI Dr. Sol Barer, Chem Systems
9:30	BREAK
9:45	Drafting Session (Continues)
11:00	ADJOURN

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27-29 August 1986
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